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REPORT ON LABORATORY INVESTIGATION OF A POLYELECTROLYTE, NALCO 600

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Laboratory Investigation of
a Polyelectrolyte
NALCO 600

by

Jesse M. Cohen

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Public Health Service
Robert A. Taft Sanitary Engineering Center
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Introduction

Since the last report on the laboratory investigation of Separan 2610, additional work has been done on another polyelectrolyte. Work on still another commercial polyelectrolyte is now in its initial stages.

The technical literature continues to be notably lacking in data on the effectiveness of these compounds in sanitary chemistry applications. The single exception is a paper by Carl E. Johnson in Industrial and Engineering Chemistry, 48, 1080, (1956), "Polyelectrolytes as Coagulants and Coagulation Aids". That a widespread interest in these new compounds exists is evident from the inquiries coming into this station and from the increased awareness of the technical people that such compounds are being developed.

Completion of work with the third commercial polyelectrolyte will represent the extent of the present phase of the investigation of polyelectrolytes. No further extensive study is anticipated at this time. This decision is based on several considerations, including:

1. Complete lack of information on chemical composition.
2. Incomplete data on toxicity and hence the reluctance to study a compound where use in municipal water is questionable.
3. The lack of an analytical procedure, and the fact that none is anticipated without the necessary chemical knowledge of composition.

The objectives of these investigations have been restricted, because of the above reasons, to these goals:

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1. Determine how polyelectrolytes behave under varying conditions.
2. Determine what their contribution was to coagulation.
3. A brief survey of the range of usefulness in the sanitary chemical field.

Polyelectrolyte Selected

With almost 20 commercial samples of polyelectrolytes on hand, it was obviously necessary to restrict the investigation to a study of only a few. It would have been desirable to select the compounds which were chemically representative of a group, but since the chemical composition is unknown in all cases, such a basis for selection was not possible.

Nalco 600 was chosen for the second compound to be studied because:

1. We had been informed that Nalco 600 was entirely different from Separan 2610, the first compound studied.
2. It is sold as a solution in contrast to the powder form of Separan 2610.
3. The manufacturer is actively promoting the use of Nalco 600 in potable water applications.

What Is It?

Nalco 600 is produced by National Aluminate Corporation, and is described as an outstanding new type of "coagulant". The company further claims that it is a "polyelectrolyte which reacts very quickly with minute particles in water and coagulates them into a rapidly settling

floc. It increases throughput rates in clarification equipment, replaces other coagulants or permits reduction in dosage of other coagulants by as much as 50%".

Nalco 600 is supplied as an amber colored, slightly viscous, caustic liquid. This solution contains an organic polycationic polymer in an approximately 1 N caustic solution. Since it is miscible in all proportions with water, dilute solutions for feeding in water treatment are readily made.

Toxicity

No precautions are advised in handling Nalco 600 other than those that would apply to any caustic solution, i.e. avoid skin splashes, etc. The material is corrosive to copper and copper alloys, again a precaution related to the causticity.

A subacute oral toxicity investigation on Albino rats was performed by National Aluminate Corporation.

Three groups of Albino rats, consisting of 25 male and 25 female per group, were fed daily with Nalco 600. One group served as a control. Table I shows the dose schedule.

TABLE I

Test Group	Conc. NALCO 600 ppm or µl/l	Range of daily water consumption ml days 1-30	31-120	Range of daily dose NALCO 600 µl	
1	1	30 - 40	40 - 60	.3 - .4	.4 - .6
2	100	30 - 40	40 - 60	.3 - .4	.4 - .6
3	1000	30 - 40	40 - 60	30 - 40	40 - 60

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1	10	30 - 40	40 - 60	.3 - .4	.4 - .6
2	100	30 - 40	40 - 60	.3 - .4	.4 - .6
3	1000	30 - 40	40 - 60	30 - 40	40 - 60

The conclusions of this study are:

1. Daily administration of Nalco 600 to Albino rats during the 120 day test period did not result in any symptoms of either local or systemic intoxication.
2. The growth rate, general activity, and behavior of the animals during the investigation were normal.

From the data given it is evident that there were no short term toxic effects from feeding Nalco 600 in amounts up to 1000 ppm via the water supply to 150 adult rats. Both histopathological and hematological surveys were conducted at intervals during the 120 day test period. From these data it is safe to presume that Nalco 600 is at least of a low order of toxicity. However, before an unqualified approval can be given, at least another species of animal other than a rodent should be tested. Also, a longer term study should be conducted to determine if there are any long term or latent toxic effects that might materialize after continuous ingestion of chronic levels of Nalco 600.

Experimental Data

Synthetic Turbid Water

Initial experimental work with Nalco 600 was done with a "Synthetic turbid raw water" which has been in use in this laboratory as a standard water for over 3 years. Since this water is easily reproducible, any changes in the quality of a coagulation obtained could be justifiably ascribed solely to any added variable. Thus, improvements in coagulation by adding Separan, for example, could only be due to this compound and not to a change in the quality of the test water.

Early in our work we discovered that benefits from the use of Nalco 600 could not be obtained with the synthetic turbid water. Further work showed that Nalco 600 had no effect on coagulation when mineralization was low or absent. However, when clay was added to Cincinnati tap water, increased settling rates were obtained with Nalco 600 application. Since this lack of activity of Nalco 600 in an unmineralized water precluded using the standard synthetic turbid water, Cincinnati tap water with clay turbidity added was used in the first phases of the investigation.

Analytical Procedure

The usual six-place stirrer was used in all instances to flocculate six 2 liter volumes of water. A coagulation test consisted of (1) addition of chemicals, (2) stirring for 30 minutes, followed by, (3) quiescent settling for 30 minutes. Determination of the time of first visible floc, settling rate, and other pertinent determinations were made on most effluents. The criteria for a coagulation were settling rate of the floc and 30 minute residual turbidity.

Turbid Cincinnati Tap Water

pH 7.4 - 8.6; alkalinity 42-52 ppm; hardness 140-150 ppm.

For optimum results the time of addition of polyelectrolyte to a coagulation is quite important. Some increase in settling rate was obtained when Nalco 600 was added before or simultaneously with alum. Best results occurred when Nalco 600 was added 1 - 2 minutes after alum. In subsequent work Nalco 600 was routinely added one minute after the alum addition.

Maximum benefits are obtained with Nalco 600 over a relatively narrow range of concentration. With 10 ppm of alum in turbid Cincinnati tap water, good results (high settling rate plus low residual turbidity) were obtained with 1 - 4 ppm of Nalco 600. Increased doses, 6 - 8 ppm, generally gave decreased settling rates and increased residual turbidities. Doses beyond 8 ppm interfered with coagulation sometimes to the point of complete inhibition.

No relationship was found between the amount of turbidity present and the amount of Nalco 600 required. Increased amounts of Nalco 600, however, were required as the alum dose was raised. This relationship is not linear as it was with Separan.

Addition of Nalco 600 does not significantly shorten the flocculation time, although a rapid settling rate and a satisfactory effluent were obtained when a 20 minute, instead of 30 minute, flocculation period was used. Effluent quality was somewhat poorer than that obtained with the full 30 minute period of flocculation as measured by residual turbidity.

Nalco 600 does not extend the range of pH in which alum coagulation can be accomplished. With turbid Cincinnati tap water, the pH range within which good coagulation was obtained with 10 ppm alum coagulation, was narrow, 7.0 - 8.2; addition of Nalco 600 improved the coagulation only at these pH's.

Nalco 600 was effective with ferric sulfate coagulation. From the single test made, it appears that less Nalco 600 is required with ferric sulfate than with alum. Highest settling rate was obtained

with 2 ppm Nalco 600 when ferric sulfate was used, while 4 ppm were required with alum. Interference with congulation occurred with lower doses of Nalco 600 when using ferric sulfate than when alum was the congulant.

Natural Waters

The fact that Nalco 600 was ineffective in our synthetic turbid water, and in other test waters with low mineral content, indicated that the type of water being tested was an important consideration. The time of addition and optimum concentration of Nalco 600 to use was determined on several local waters. Twenty-five gallons of the water under test were collected at one time and combined in a large tank equipped with a stirrer to ensure that water of unvarying composition was being studied.

Ohio River Water

pH 7.5; Alkalinity 61 ppm; hardness 141 ppm; turbidity 98.

Greatly accelerated settling rates were obtained when Nalco 600 was added just before, simultaneous with, and 1 - 5 minutes after the alum congulant addition. The greatest settling rate, however, was obtained when Nalco 600 was added 1 minute after alum, when alum floc is just visible. Eight ppm of Nalco 600, plus 20 ppm alum, were required for optimum results. Concentrations of Nalco 600 in excess of this amount, 16 - 20 ppm, generally interfered with congulation. This interference did not occur when Nalco 600 was added at a time when the alum floc was fully formed.

Eight ppm of Nalco 600 alone - no additional coagulant - accomplished a fair clarification of the water which would probably be suitable for application onto a sand filter. The addition of 4 ppm of Nalco 600 enabled a reduction of the alum dose from 20 ppm to 10 ppm. A comparison between Separan and Nalco 600 showed that the Separan floc was slightly larger and hence gave a greater settling rate in the first 2 minutes of settling; thereafter the settling rates were identical.

Figure 1 shows the settling rates obtained under the indicated conditions.

While some clarification was obtained, using 8 ppm of Nalco 600 as the coagulant, the residual turbidity was high. The combination of 8 ppm of Nalco 600 and 20 ppm of alum produced an acceptable effluent within 2 - 3 minutes of settling, while 60 minutes were required to achieve the same quality of water with alum as the coagulant.

Little Miami River Water

pH 8.0; alkalinity 179 ppm; hardness 228 ppm; turbidity 124.

All concentrations of Nalco 600 tested, 4 - 20 ppm, gave excellent settling rates with 20 ppm of alum regardless of when the polyelectrolyte was added - before, 1 minute, or 5 minutes after alum. The addition of 12 ppm Nalco 600 one minute after alum, however, gave somewhat superior results. Incidentally, this small difference in coagulation quality would probably not be observed visually, and it is apparent in our work only because of our method of evaluating floc quality, i. e, settling rate determination. No interference with coagulation was observed with concentrations of Nalco 600 as high as 20 ppm. Eight to 16 ppm of Nalco 600 alone accomplished a fair clarification.

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The alum requirement can be drastically reduced, from 20 to 2.5 ppm, when 6 ppm of Nalco 600 are added; not, however, without some sacrifice in the quality of the effluent. Residual turbidity increases as the alum dose is reduced. When the flocculation time was reduced from 30 to 5 minutes, acceptable effluents were produced with 5 minutes of settling when alum plus Nalco 600 was used, while at least 30 minutes settling was required with alum alone. Residual turbidities were somewhat higher than when a 30 minute flocculation time was used.

A comparison between Separan and Nalco 600 showed that their behavior was quite similar, with the latter yielding somewhat superior results.

Figure 2 shows the settling rates obtained with alum alone, Nalco 600 alone, and Alum-Nalco 600, with the latter obviously the best coagulation.

Bryant's Pond Water

pH 7.7; alkalinity 55 ppm; hardness 57 ppm; turbidity 95.

In spite of the fact that the alum demand of this water was relatively high, 30 ppm, surprisingly small doses of Nalco 600 were effective. As little as 0.5 ppm Nalco 600 effectively increased the settling rate. Best results were obtained when Nalco 600 was added 1 - 5 minutes after alum. No significant interference was encountered with doses of Nalco 600 as high as 24 ppm. The floc produced in these coagulations were quite unusual; they were so light and sticky that after 30 minutes of flocculation, practically no floc was present in the body of the water; floc was either floating in large rafts or was

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sticking to surfaces such as the jar sides, paddle and sampling tube. This could be a serious problem in a water plant. Sixteen ppm of Nalco 600 alone - no alum - gave results fully as good as Nalco 600 - alum coagulations. At least a 50% reduction of the alum requirement could be obtained by the addition of 4 ppm of Nalco 600. In this instance, 25 ppm of alum plus 4 ppm of Nalco 600 gave results which were superior to the use of 50 ppm of alum alone. Even smaller amounts of alum, 10 ppm in contrast to 50 ppm, in conjunction with 4 ppm Nalco 600 could also be used, but with some sacrifice in effluent quality. Figure 3 shows the improvement of the settling rate obtained with Nalco 600 addition to alum coagulation. The coagulation, using 4 ppm Nalco 600 plus 50 ppm alum, yielded an acceptable effluent within 2 - 3 minutes of settling, while 50 ppm of alum required a settling period of at least 30 minutes to produce an equivalent effluent.

Mill Creek Water

pH 7.5; Alkalinity 231 ppm; hardness 936 ppm; turbidity 100; oxygen consumed (dichromate) 113 ppm.

Mill Creek is a small stream which receives a large and varied industrial waste load. It was selected to enable a study of the effect of Nalco 600 on a highly polluted water. Effective alum coagulation of this water could only be obtained with very high doses, at least 150 - 180 ppm. The floc produced, even at these high doses, was very fine and settled poorly. The addition of 40 ppm of Nalco 600 to the 150 ppm alum reversed the condition of small fine floc to a large rapidly settling coagulation. At the end of 3 minutes of settling, the alum alone, with

no Nalco 600 addition, had removed only 18% of the turbidity (residual turbidity being almost all fine alum floc) compared to 82% obtained with the Nalco 600 addition.

Coagulation with Nalco 600 alone was not too effective. While some flocculation did occur, clarification was incomplete. Substantial reduction in alum dose could be achieved; 50 ppm alum plus 30 ppm Nalco 600 gave a fast settling floc and good effluent.

Figure 4 summarizes the above statements. With alum alone the floc was so fine that in the first 2 minutes of settling, turbidity values were actually higher than the starting turbidity. Forty ppm of Nalco 600 added to this coagulation effectively increased the floc size to give a rapidly settling floc.

Further Effects of Nalco 600

In the preceding discussion on the behavior of Nalco 600 alone and in conjunction with alum, the principal benefits obtained were (1) increased settling rate of the alum floc; (2) decreased alum requirement; (3) decreased time of flocculation. These benefits are derived fundamentally from the effect of Nalco 600 on clay and metal coagulant particles. Because polyelectrolytes are multicharged electrically, it was presumed that the effect on specific soluble or suspended substances would be a promising area for investigation. Accordingly, several materials were studied briefly with the view of overcoming some of the difficulties in coagulation presented by these materials by the application of Nalco 600.

Sodium Tripolyphosphate

A major ingredient of synthetic detergents are the polyphosphates, of which tripolyphosphate is the most important. Previous studies in this laboratory had shown that small amounts of this material caused interference and even complete inhibition of alum coagulation of soft water.

Under the conditions of our test water, Cincinnati tap water with added clay turbidity, 4.0 ppm of sodium tripolyphosphate completely prevented coagulation with 10 ppm alum. When 4.0 ppm of Nalco 600 were added, this interference was eliminated even in the presence of up to 12 ppm sodium tripolyphosphate. Excellent coagulation was obtained, with a high settling rate and low residual turbidity.

No determination for residual tripolyphosphate was made, although experience has shown that essentially complete removals are obtained when a good coagulation occurs.

Lignin Compound

Lignin compounds in water supplies not only produce colors that are difficult to remove, but they also are difficult to treat by coagulation. Greatly increased amounts of alum are required when lignin compounds are present, and the floc is fine and slow settling. Seven ppm of Orzan S, a sodium lignosulfonate, completely inhibited coagulation with 15 ppm alum in turbid Cincinnati tap water. When 5 ppm of Nalco 600 was added, good coagulation was obtained even in the presence of twice the amount of Orzan S, or 14 ppm. The settling rate was decreased as Orzan S concentration increased but, in all cases, a very satisfactory coagulation was obtained.

Synthetic Detergents

The effect of the various components of synthetic detergents on the coagulation of water has been studied in this and other laboratories. Results to date indicate that the surfactant portion does not interfere with coagulation, but, more important, that normal coagulation does not remove significant amounts of the surfactant. Concentrations of surfactant in the finished water are only 5 - 10% less than in the untreated water supply. Surfactants can be removed only by heroic treatment with high concentrations of activated carbon. Concentrations as low as 1.0 to 1.5 ppm of surfactant have caused foaming complaints in finished waters.

Water containing 10 ppm of a purified alkylbenzenesulfonate was coagulated with 15 ppm alum and increasing amounts of Nalco 600 ranging from 2 to 16 ppm. Concentrations of surfactant were determined before and after coagulation. The control, alum alone, showed the expected 6% removal of surfactant, while increasing amounts of surfactant, up to 45%, were removed by the Alum-Nalco 600 coagulations. Attempts to effect a greater removal with increased amounts of Nalco 600 failed, for as the Nalco 600 was increased, interference with coagulation due to Nalco 600 began to operate with concomitant decreased surfactant removal.

The removal of surfactant by Nalco 600 is apparently an adsorption phenomenon. When the data are plotted according to the Freundlich adsorption equation a linear relationship is found between removal of surfactant and Nalco 600 application. Figure 5 shows this plot.

Algae

Recovery of algae from oxidation ponds by means of coagulation promises to have considerable importance, particularly if this can be done without producing a sludge of high inorganic content, such as is obtained with alum coagulation.

A further application of coagulation of algae by polyelectrolytes could be in the analytical procedure for algae enumeration. Present methods for concentrating the algae are not entirely satisfactory.

A unialgal culture of Chlorella was inoculated into a modified Gerloff's medium, which contains the following ingredients per liter:

Calcium Nitrate	$Ca(NO_3)_2\ 4H_2O$	116 mg
Potassium Sulfate	K_2HPO_4	10 mg
Magnesium Sulfate	$MgSO_4\ 7H_2O$	25 mg
Sodium Carbonate	Na_2CO_3	20 mg
Sodium Silicate	$Na_2SiO_3\ 5H_2O$	44 mg
Citric Acid		3 mg
Ferric Citrate		3 mg

The culture was then incubated until a heavy growth of algae was obtained. Microscopic count showed that 8 million cells per ml of Chlorella were present.

Separate aliquots of this culture were treated with increasing amounts of Nalco 600 by stirring for one hour and then allowing the samples to stand for one hour. Samples of the supernatant were withdrawn at intervals for turbidity measurement* and microscopic counting,

*Turbidity measured with a spectrophotometer was used to roughly indicate the numbers of algal cells present.

Figure 6 snows that Nalco 600 additions up to 40 ppm did not coagulate the algae. Good coagulation was obtained with 80 ppm, with the floc (agglomerated algae) almost completely settled within 5 minutes. Settling overnight gave only slightly better effluents. Complete coagulation was obtained with concentrations of Nalco 600 above 120 ppm.

The per cent removals of algae obtained with the various Nalco 600 treatments are shown in Table II. Algae enumerations were done microscopically by Dr. C. M. Palmer.

TABLE II

Sample	Cells/ml	% Reduction
1. Untreated culture	8,000,000	
2. 0 ppm Nalco (control)*	8,000,000	0
3. 40 ppm Nalco	8,000,000	0
4. 80 ppm Nalco	1,500,000	81
5. 120 ppm Nalco	25,000	99.7
6. 160 ppm Nalco	25,000	99.7
7. 200 ppm Nalco	20,000	99.8

* This sample was stirred for 1 hour and settled for 1 hour with no apparent reduction in concentration of algae.

Figure 6 also shows that even at the highest Nalco 600 concentration, 33% of the original turbidity resisted removal and was present in the effluent as a very fine clay-like whitish (as opposed to a greenish color for algae) turbidity. Microscopic examination quickly showed that the algae culture was heavily contaminated with an apparently pure culture of a micrococcus. It is not clear, at this time, why Nalco 600

failed to coagulate these negatively charged bacteria, when the equally negative algae were so effectively agglomerated.

Further work, as time permits, will be done on coagulation of various kinds of algae in different waters by using polyelectrolytes.

Sewage

The possibility of increasing the efficiency of primary sedimentation of raw sewage by adding small amounts of a coagulant which do not produce the inorganic bulk that metal coagulants do, prompted the brief study of sewage coagulation by Nalco 600. Increased removal of suspended solids was indeed obtained with Nalco 600 treatment, but the quantities of reagent necessary for this operation were unreasonable. Doses of 200-400 ppm of Nalco 600 were required to obtain a 15-20% increase in removal of suspended material.

Because of the disappointing results of these few tests, this work was not pursued any further.

Biological Stability

There is some evidence in the technical literature on polyelectrolytes that the bulk of this compound added to a coagulation would be removed by adsorption. In fact, the mechanism of coagulation with these polyelectrolytes is said to be dependent on adsorption and bridging of these compounds between suspended particles. However, without an analytical method, the completeness of removal of polyelectrolytes cannot be ascertained, and the presumption is that some may remain in the effluent and would be discharged to a stream or sewage plant.

With that in mind, some determinations of stability to biological oxidation were made. The standard 5-day BOD showed that Nalco 600 was remarkably stable to biological oxidation even when seeded with Ohio River water and sewage.

Cost Estimates of Nalco 600 Treatment

At this point it would be instructive to make some estimates of the chemical cost of treating water with Nalco 600. For the purposes of calculation the following prices were used. Alum, containing 16% aluminum, delivered to Cincinnati costs 1.98 cents per pound. The price of Nalco 600, quoted on a small lot, was 35.5 cents per pound. This figure may be somewhat lower on larger orders but will suffice for the purpose of these calculations. With these prices, then, each ppm of Nalco 600 is equivalent in cost to 17.9 ppm of alum.

Cost Estimates

Water	Alum ppm	Nalco 600 ppm	Dollars per million gallons
Ohio River	20	0	3.31
" "	10	4	12.09
Bryant's Pond	50	0	8.26
" "	25	4	15.96
	0	16	47.21
Algae	--	80	236.00

It is obvious from these comparative costs that routine treatment with Nalco 600 is expensive. The concentrations of Nalco 600 shown in the above table may be high since the doses represent the concentration

needed to give maximum settling rate. Lesser concentrations probably could be used with only slightly lower settling rates.

Nalco 600 would be helpful in the following cases:

1. When the normal alum requirement of a water is very high and can be substantially reduced by using a few ppm of Nalco 600.
2. During temporary periods of coagulation difficulty, when cost of chemicals is secondary to the production of a good effluent.
3. When plant capacity is inadequate, sedimentation time is reduced by Nalco 600, enabling a higher rate of flow through the sedimentation basins.

Implications of Reported Work

It should be emphasized that much of the above conclusions was based on a single or at most only a few experiments, and that generalizations on conditions other than those described are probably not justified at this time. It is believed that the objectives of this study were fulfilled by this brief survey of the potentialities of Nalco 600. Further extensive work on this compound is not planned until knowledge of the composition, toxicity, and analytical chemistry of Nalco 600 becomes available.

This report is the second issued on the work done here on polyelectrolytes. The first report covered the study of Separan 2610. In Table III are tabulated some of the differences observed between Separan 2610 and Nalco 600.

TABLE III

Observed Differences Between

Separan 2610 and Nalco 600

Item	Separan 2610	Nalco 600
1. Form	Powder	Caustic Solution
2. Alum-polyelectrolyte coagulation of natural waters	Good	Good
3. Polyelectrolyte alone coagulation of natural waters	No coagulation	Fairly good
4. Reduction of alum dose	Slight	50 - 75%
5. Removal of surfactant	No effect	Up to 45%
6. Coagulation of algae	No	99.8% removed
7. Stability to biological oxidation	About 12% oxidized	Stable
8. Behavior in Presence of Sodium tripolyphosphate	No benefits	Tolerance increased by factor of 3
9. Behavior in Unmineralized Water	Good	Slightly beneficial
10. Effect with lignin compound	No benefits	Tolerance increased at least by factor of 2

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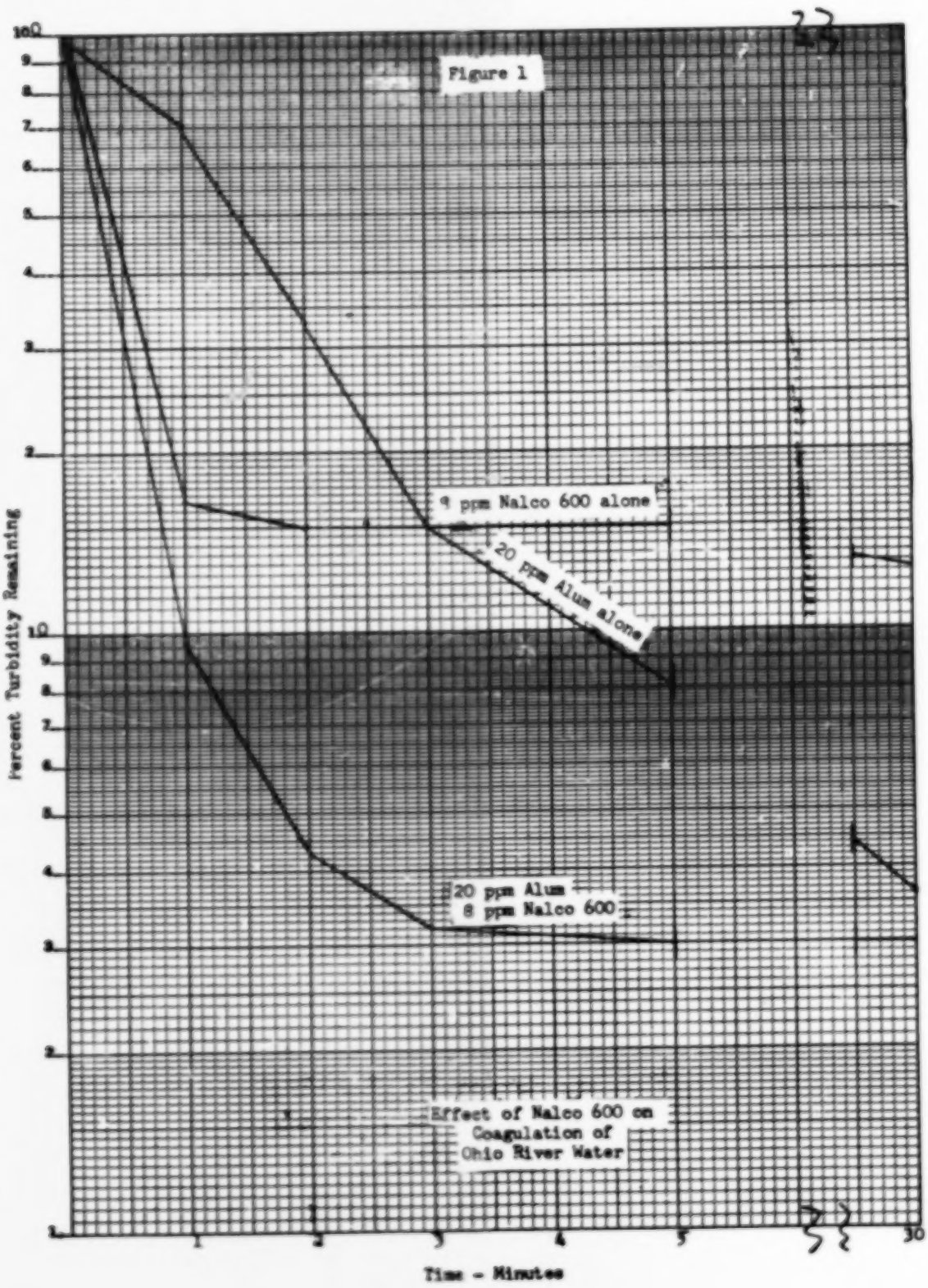


Figure 1
9 ppm Nalco 600 alone
20 ppm Alum alone
20 ppm Alum
8 ppm Nalco 600
Effect of Nalco 600 on
Coagulation of
Ohio River Water
Percent Turbidity Remaining
Time - Minutes
100
10
1
1
2
3
4
5
30

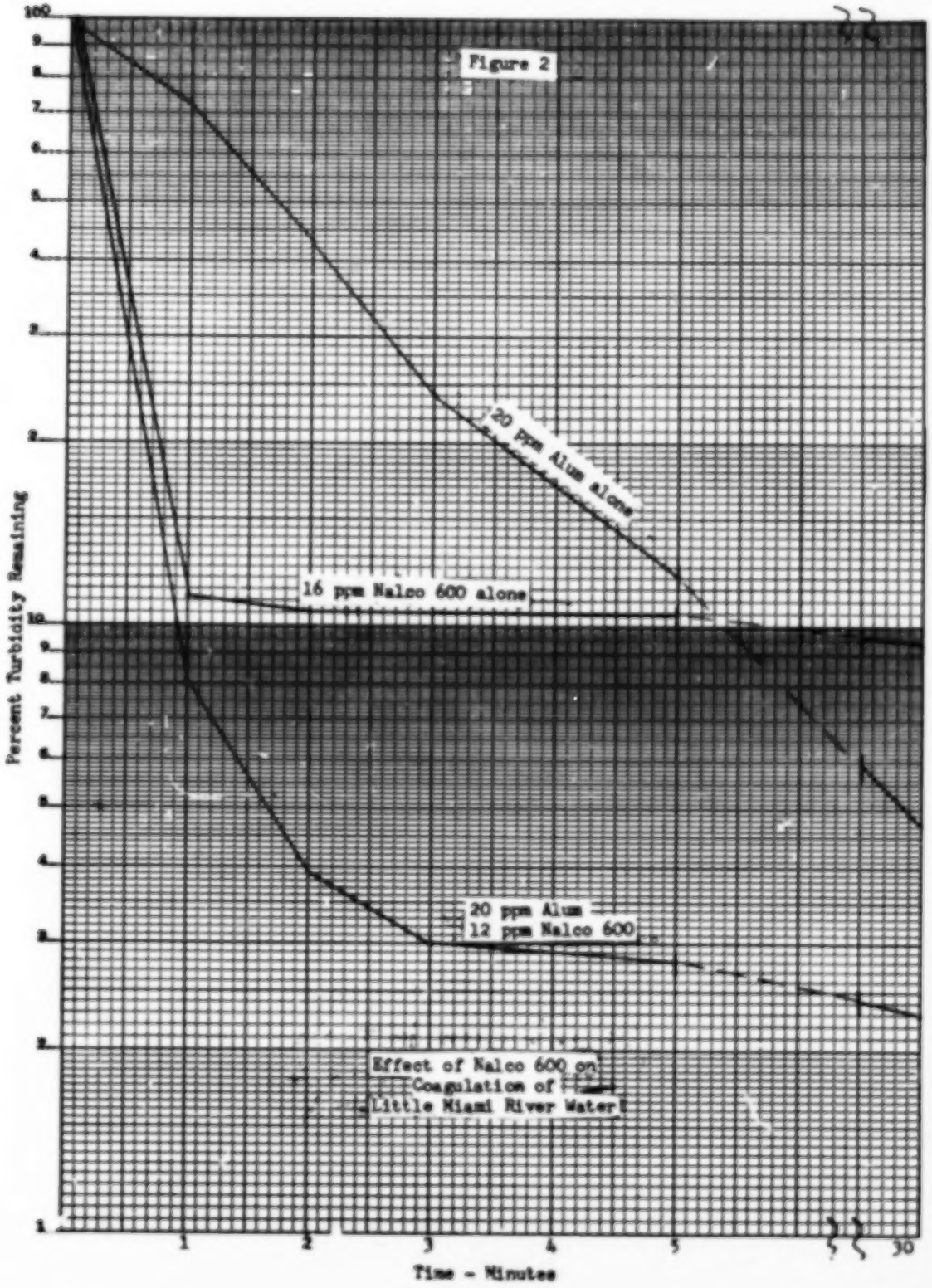


Figure 2
20 ppm Alum alone
16 ppm Nalco 600 alone
20 ppm Alum
12 ppm Nalco 600
Effect of Nalco 600 on
Coagulation of
Little Miami River Water
Percent Turbidity Remaining
Time - Minutes
100
1
2
3
4
5
30

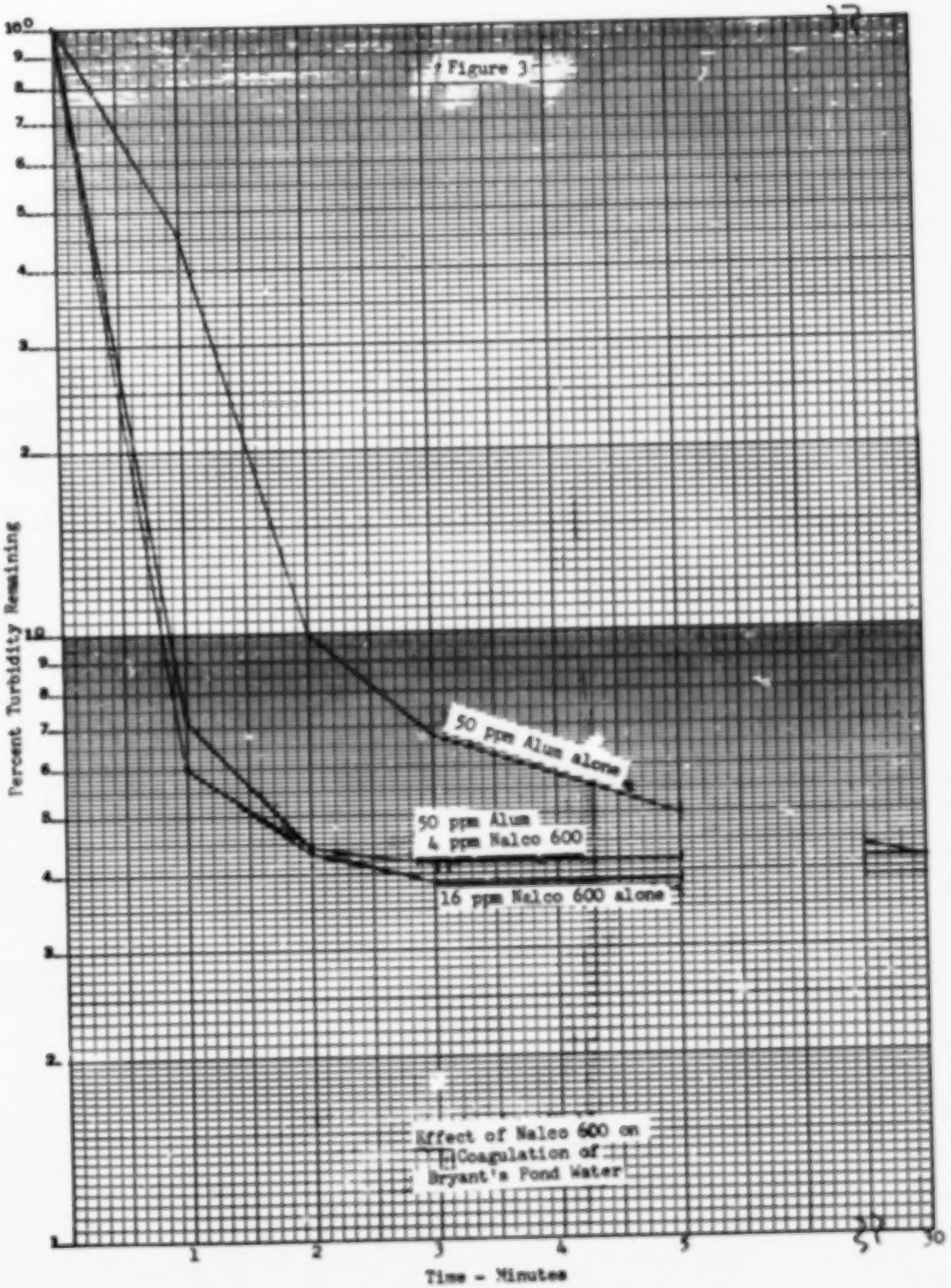
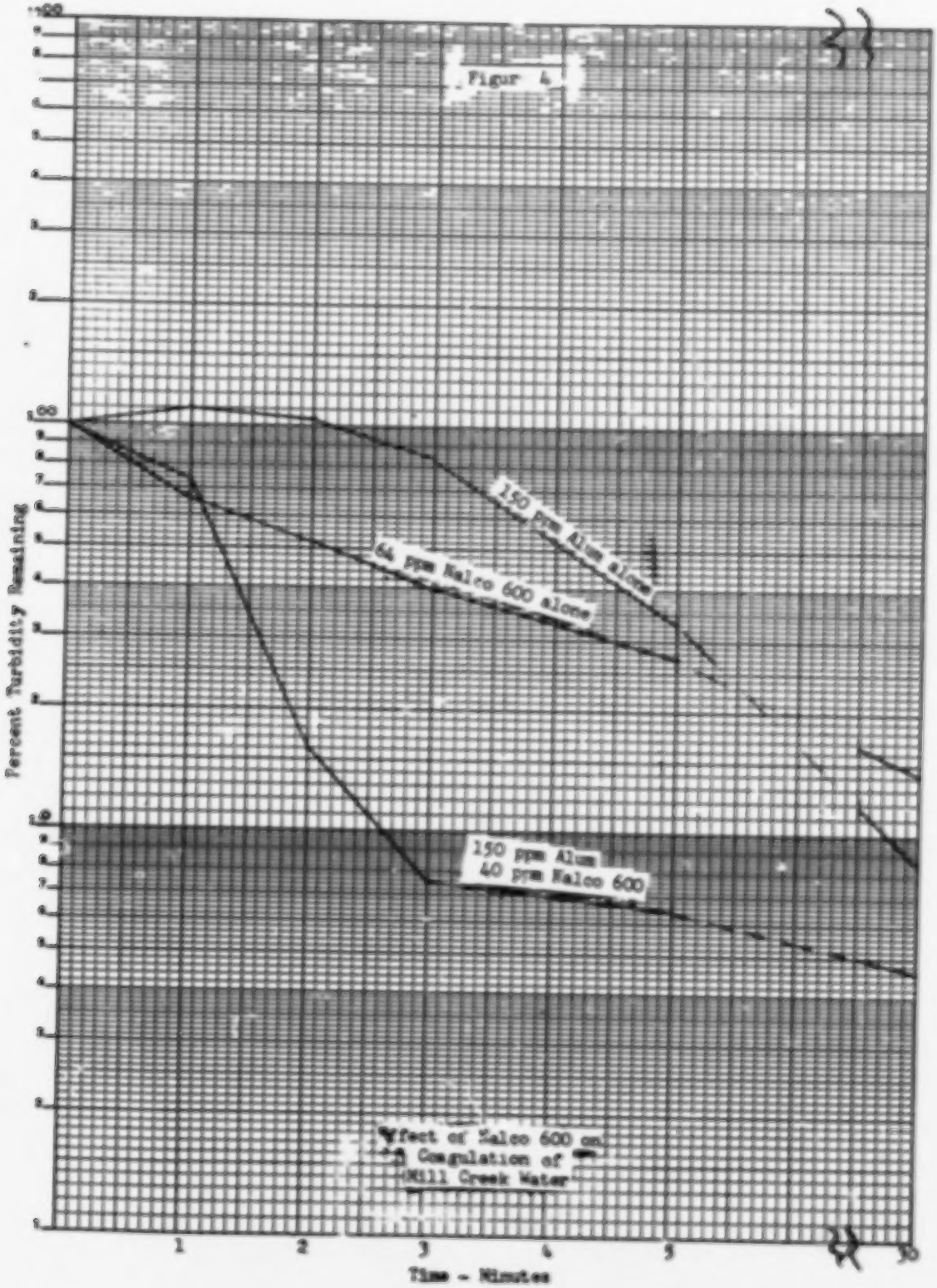


Figure 3
Percent Turbidity Remaining
100
90
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
2
1
50 ppm Alum alone
50 ppm Alum
4 ppm Nalco 600
16 ppm Nalco 600 alone
Effect of Nalco 600 on
Coagulation of
Bryant's Pond Water
1
2
3
4
5
10
Time - Minutes


Figur 4
Percent Turbidity Remaining
100
80
60
150 ppm Alum alone
44 ppm Nalco 600 alone
150 ppm Alum
40 ppm Nalco 600
Effect of Nalco 600 on Coagulation of Mill Creek Water
1
2
3
4
5
30
Time - Minutes

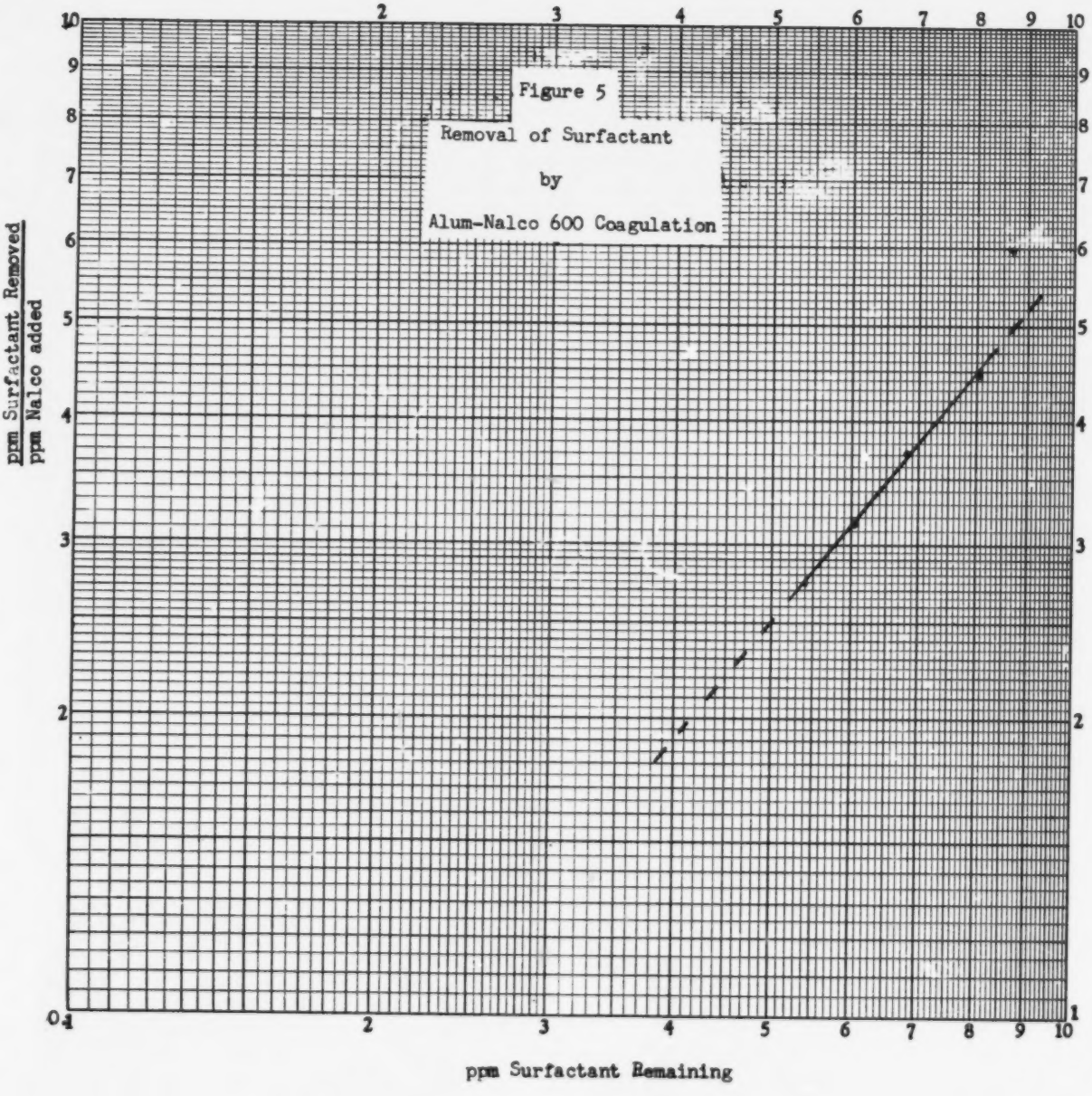


Figure 5
Removal of Surfactant
by
Alum-Nalco 600 Coagulation
ppm Surfactant Removed
ppm Nalco added
ppm Surfactant Remaining
0
1
2
3
4
5
6
7
8
9
10

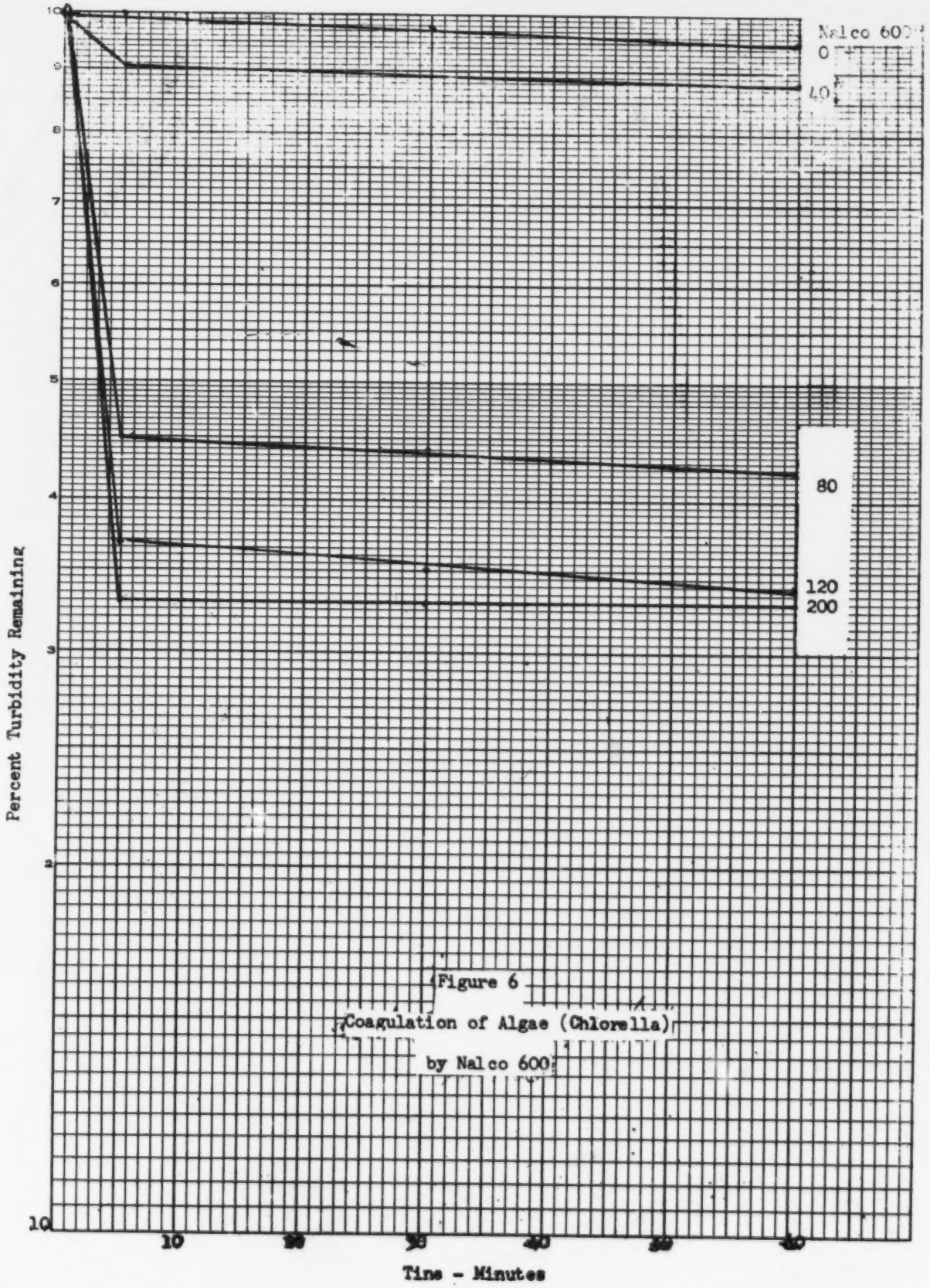


Figure 6

Coagulation of Algae (Chlorella)

by Nalco 600